Physics … CS 114

1st Class/ Department of Communications Engineering and Smart Digital Systems

Bologna process –1st Semester 26-27

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Atoms and Semiconductors

Department of Communications and Intelligent Digital Systems Engineering

CS114 Physics

Energy Levels and Atomic Structure

- Atomic Models: Thomson's "Plum Pudding," Rutherford's Nuclear Model, Bohr Model.
- Quantum Concepts: De Broglie Hypothesis, Wave-Particle Duality.
- Electron Energy: Energy levels in hydrogen atoms, photon emission/absorption.
- Crystal Structure: Energy-band theory for metals, insulators, and semiconductors.
- Fermi-Dirac distribution function.

Transport Phenomena in Semiconductors

- Charge Transport: Conductivity, resistivity, drift current, electron mobility, and drift velocity.
- Diffusion Current: Current due to carrier concentration gradients.
- Work Function and Electronic Emission: Thermionic, photo, field, and secondary emission.
- Carrier Statistics: Intrinsic and extrinsic semiconductor carrier densities (n, p, n_i).
- Electrical Conduction: Conductivity in intrinsic and extrinsic (n-type and p-type) semiconductors.
- Hall Effect: Principle, Hall voltage, and coefficient for determining carrier density and type.

Semiconductor P-N Junction (Diode)

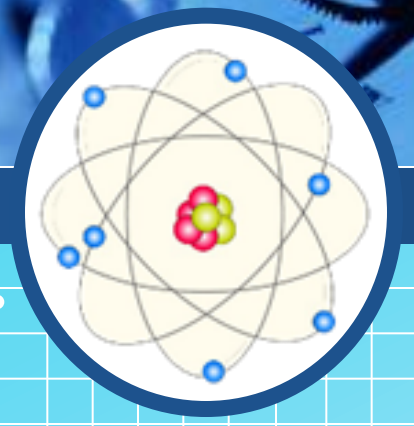
- Junction Formation: Structure, depletion region, and built-in potential (barrier potential).
- Biasing: Current-voltage characteristics under forward and reverse bias.
- Junction Capacitance: Depletion region width and capacitance calculation.
- Device Analysis: Calculating carrier densities, barrier potential, current, and depletion width.

Delivery Plan (Weekly Syllabus)

المنهاج الاسبوعي النظري

Weeks	Material Covered	
Week 1	Introduction to Atomic Models	Thomson's "Plum Pudding," Rutherford's Nuclear Model
Week 2	The Bohr Model	Bohr's Postulates, Electron Energy Levels for Hydrogen
Week 3	Quantum Foundations	De Broglie Hypothesis, Wave-Particle Duality
Week 4	Energy Band Theory	Band Formation, Conductors, Insulators, Semiconductors
Week 5	Fermi-Dirac Statistics	Fermi Function, Fermi Energy, Carrier Distribution
Week 6	Transport Phenomena I	Drift Current, Mobility, Conductivity
Week 7	Transport Phenomena II	Diffusion Current, Einstein Relation, Total Current Density
Week 8	Intrinsic & Extrinsic Semiconductors	Doping, n-type & p-type, Carrier Concentration
Week 9	**Mid-Term Exam** / The p-n Junction I	Depletion Region Formation, Built-in Potential
Week 10	The p-n Junction II	Biasing (Forward/Reverse), I-V Characteristics, Ideal Diode Equation
Week 11	The p-n Junction III	Depletion Capacitance, Junction Breakdown
Week 12	Work Function & Contacts	Electronic Emission Types, Metal-Semiconductor Contacts
Week 13	The Hall Effect	Principle, Hall Voltage & Coefficient, Determining Carrier Density
Week 14	Diode Applications	Rectifiers, Zener Diodes, LEDs, Photodiodes
Week 15	Course Review	Comprehensive Review & Problem-Solving

Electronics Physics



L e c t u r e 1

Energy Levels and Atomic Structure

University of Mosul

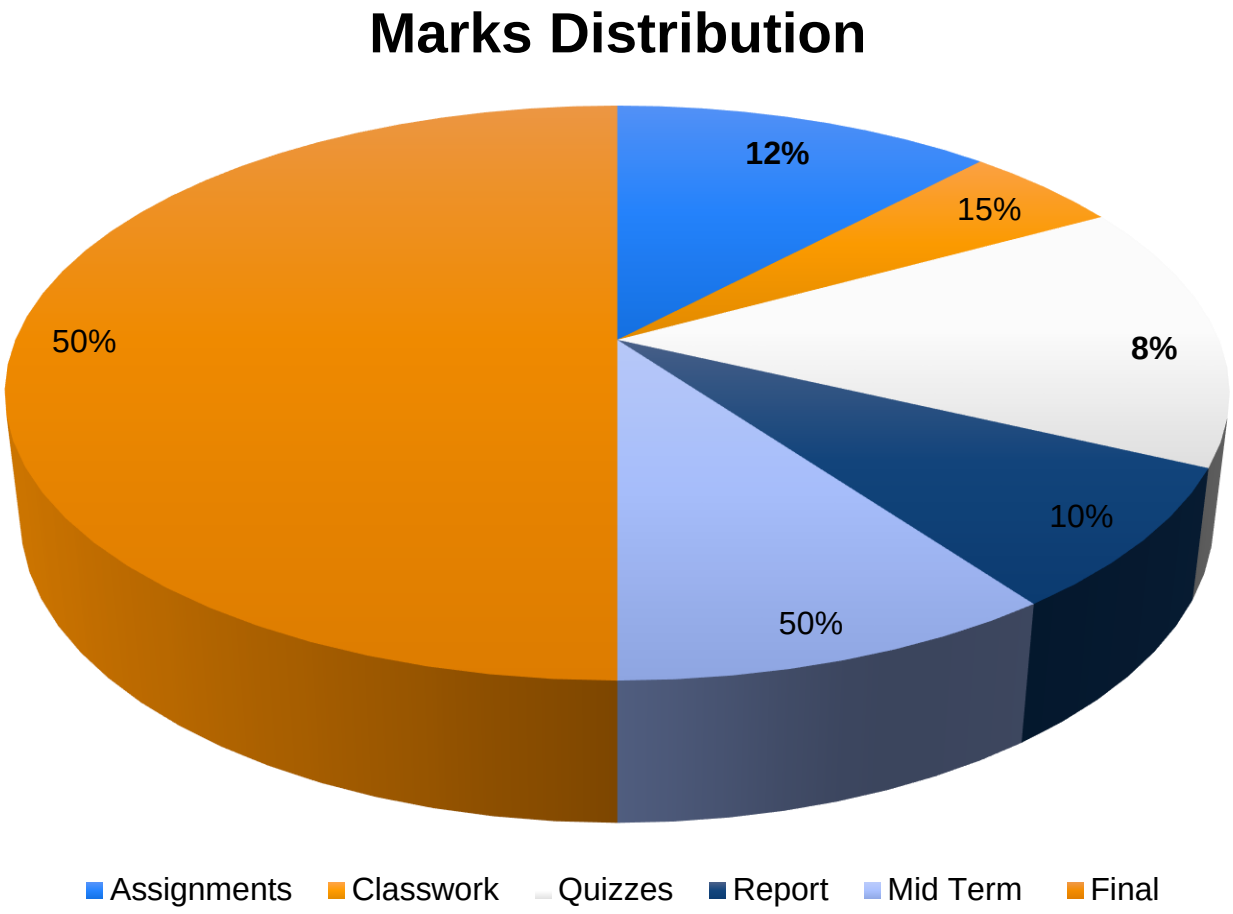
Department of Communications and Intelligent Digital Systems Engg.

Electronics Physics Outline



Unit 1	Energy Levels and Atomic Structure	Unit 2	Transport Phenomena in Semiconductor
The atom, models, wave nature of light, dual nature of matter, energy-band theory of metals, insulators and semiconductors, crystal structure, ionic, covalent and metallic bonding, energy band of crystals, Internal structure of materials cell, packing miller indices, crystal planes and directions.		Mobility and conductivity, energy distribution of electrons, Fermi levels, work function, electronic emission. Semiconductors: Semiconductors materials (Si, Ge and compound semiconductors), extrinsic semiconductors, Fermi-level in semiconductor, diffusion and carrier life time, Hall effect.	
Unit 3	**Semiconductors**	**Unit 4**	**Semiconductor p – n Junction**
p-n junction in equilibrium, current-voltage characteristics, charge-control description of a diode, Transition and diffusion capacitance's, diode switching times, diode models, small-signal model and load line concept, and introduction to Hetero-junctions and double Hetero-junctions.		Rectifiers, Zener diodes voltage regulators, clipping circuits, clamping circuits and wave form generation. Other Types of Semiconductor Diodes: Varactor diode, tunnel diode, photodiode and photovoltaic (solar) cell, Light emitting diode, metal electronic. Transistors Principle of Operation and type, Transistor biasing circuits, Application Circuit.	

Unit 1 - 4 Marks Distribution

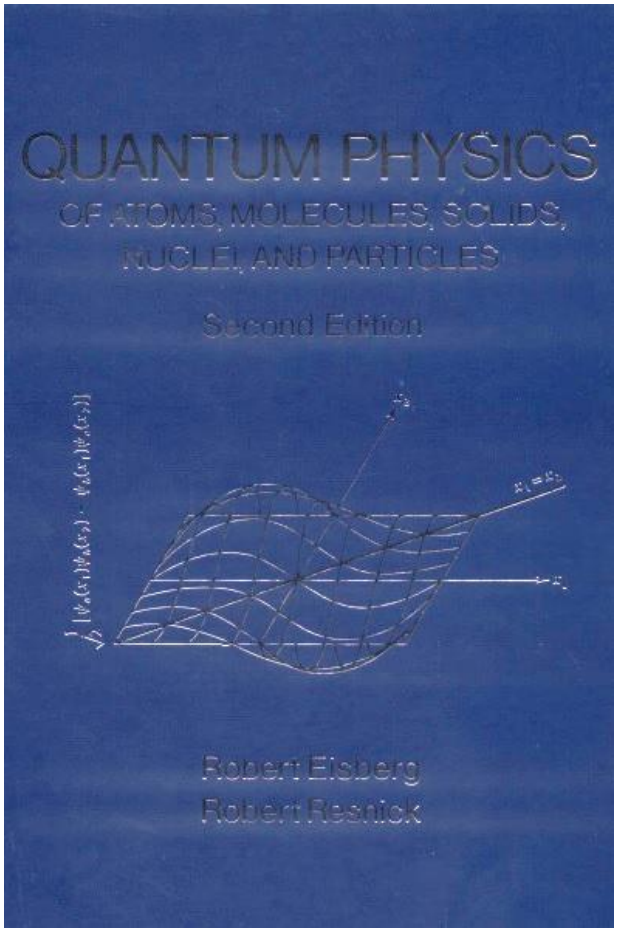


References

Quantum Physics of Atoms

By

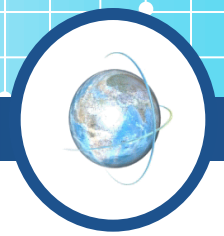
Robert Eisberg



References

Floyd, Thomas L. Electronics Fundamentals: Circuits, Devices and Applications (Floyd Electronics Fundamentals Series).

“SEMICONDUCTOR PHYSICS AND DEVICES“, by Donald. (can be downloaded from the classroom).



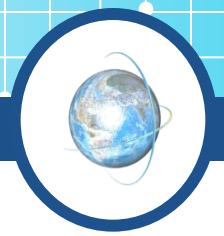
Greek Letters

alpha	α	beta	β	chi	χ	delta	δ
epsilon	ϵ	phi	ϕ	varphi	φ	gamma	γ
eta	η	iota	ι	kappa	κ	lambda	λ
mu	μ	nu	ν	pi	π	varpi	ϖ
theta	θ	vartheta	ϑ	rho	ρ	sigma	σ
varsigma	ς	tau	τ	upsilon	υ	omega	ω
xi	ξ	psi	ψ	zeta	ζ		
Delta	Δ	Phi	Φ	Gamma	Γ	Lambda	Λ
Pi	Π	Theta	Θ	Sigma	Σ	Omega	Ω
Xi	Ξ	Psi	Ψ				

List of Constants

Charge of Electron : $1.6 \times 10^{-19}\ C$	Mass of the Electron : $9.1 \times 10^{-31}\ kg$
Permittivity of Space : $8.85 \times 10^{-12}\ F\ m^{-1}$	Speed of the Light : 3×10^{8} m s^{-1}
Plank's constant : $6.62 \times 10^{-34}\ J\ s$	Boltzmann's constant : $1.38 \times 10^{-23}\ J\ K^{-1}$

Unit One Outline



Models of Atoms

- Thomson's model,
- Rutherford's model,
- Bohr model, Reduced mass,

One electron Atoms

- Electron Energy in Orbit
- Energy Level
- De Broglie Hypothesis

The energy-band theory of crystals

- Metals,
- Insulators,
- Semiconductors.

Fermi-Dirac distribution function

Models of Atoms



TO KNOW THE STRUCTURE OF THE ATOM, WE MUST KNOW THE FOLLOWING:

What are the parts of the atom?

How are these parts arranged?

- **Near the end of the 19th century, the atom was thought to be nothing more than a tiny indivisible sphere (Dalton's view). However, a series of discoveries in the fields of chemistry, electricity and magnetism, radioactivity, and quantum mechanics in the late 19th and early 20th centuries changed all of that. Here is what these fields contributed:**

Introduction



- منذ بداية القرن العشرين أصبح من المعروف أن المادة غير قابلة للتجزئة إلى ما لانهاية، بل انها تتكون من جسيمات مادية قطرها في حدود **10°A** سميت بالذرات **(Atoms)**.
- وجاءت أولى الدلائل على وجود الذرات من دراسة التفاعلات الكيميائية وسلوك الغازات كما حصل الفيزيائيون على دلائل مباشرة على وجود الذرات باستخدام المجاهر الحديثة ذات القدرة التكبيرية العالية.
- يتناول هذا المقرر دراسة تفصيلية للنماذج التي وضعها العلماء لتركيب الذرة مثل نموذج طومسون ونموذج رذرفورد و نوذج بور. وكل نموذج حقق العديد من الظواهر وفشل في أخرى وهذا ما سيتم توضيحه من خلال تناول كل نموذج بالدراسة.
- كما سيتم دراسة تركيب الذرة حيث تعتمد هذه الدراسة بشكل أساسي على فهم الطيف الكهرومغناطيسي للذرة سوف نركز من خلال هذا المقرر على طيف ذرة الهيدروجين باعتباره أبسط الأطياف الذرية والمدخل إلى بناء النماذج الذرية.

Dalton's Atomic Theory



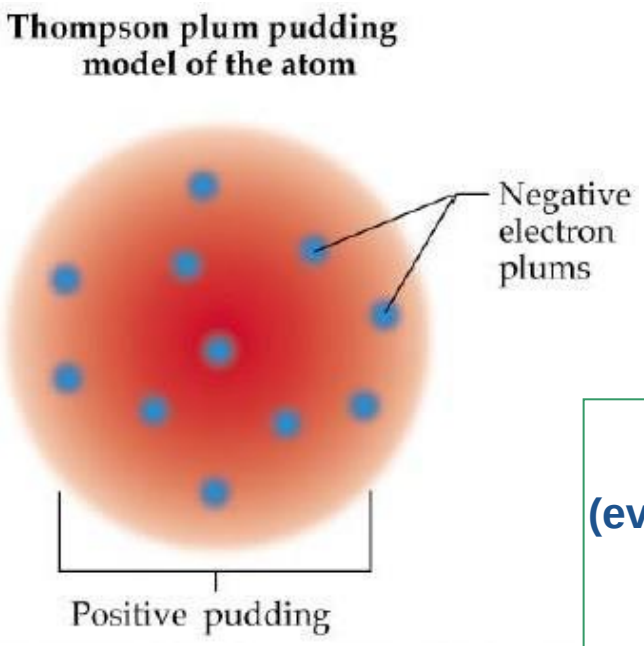
John Dalton
(1766 – 1844)

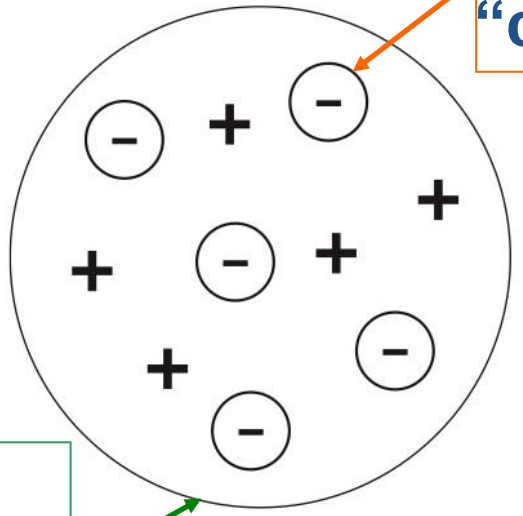
Wrote the first atomic theory

- تتكون جميع العناصر من جزيئات صغيرة غير قابلة للتجزئة تسمى الذرات
- ذرات نفس العنصر متطابقة. تختلف ذرات أي عنصر عن ذرات أي عنصر آخر.

Thomson Model: "Plum Pudding"

In 1897, J.J. Thomson used a *cathode ray tube* to deduce the presence of a negatively charged particle: the electron



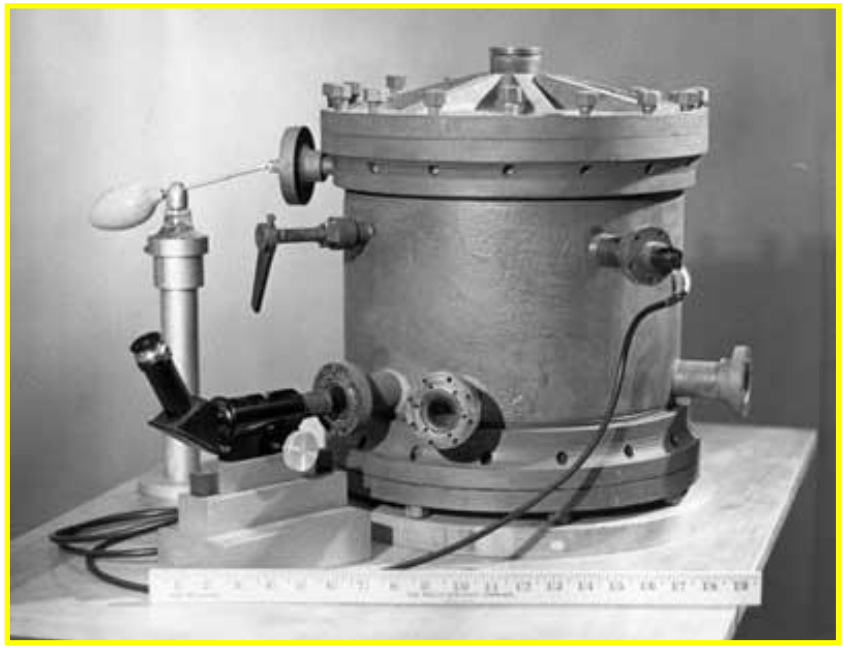


negative "chocolate"

positive (evenly distributed) "dough" part

Mass of the Electron

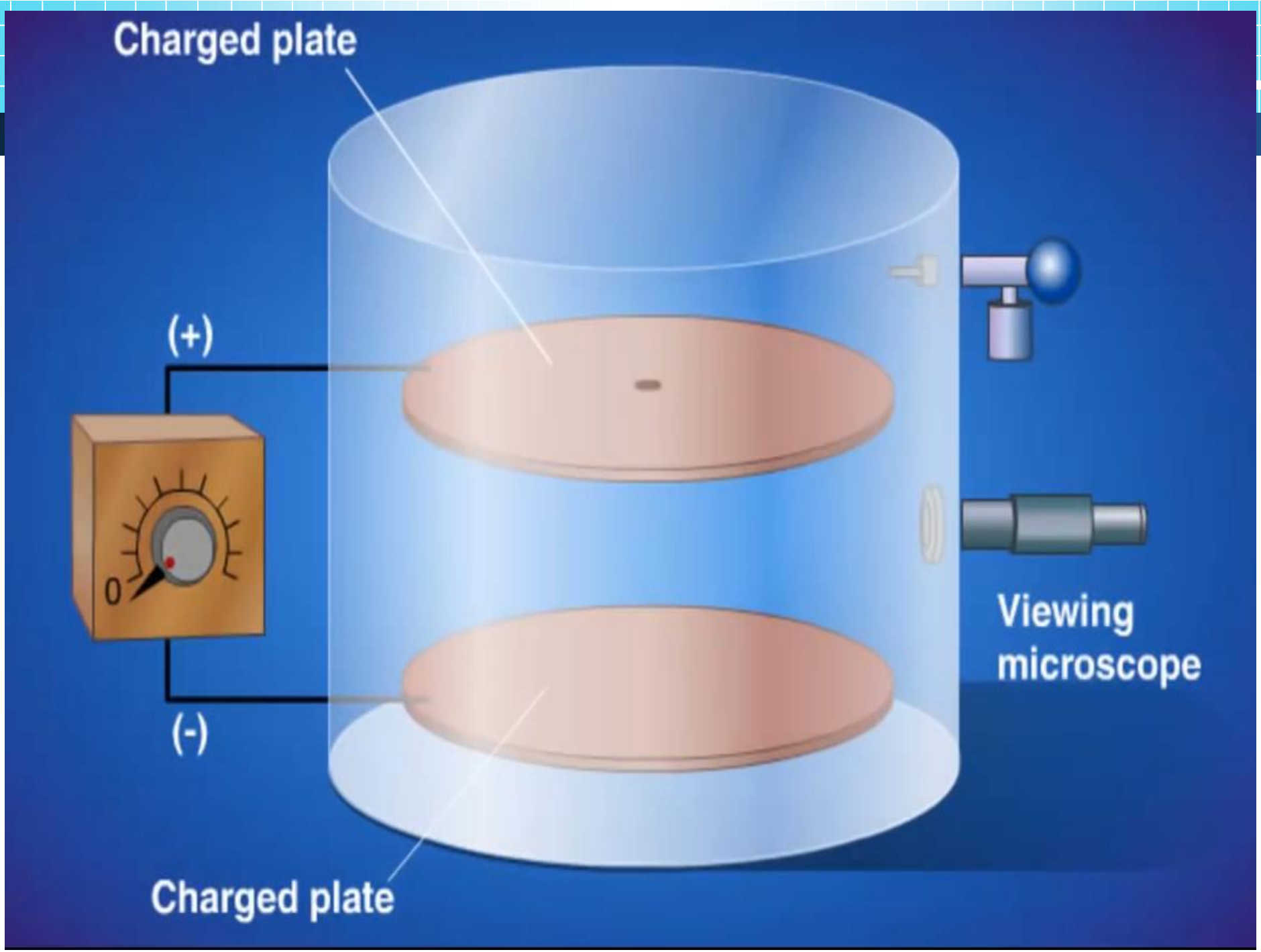


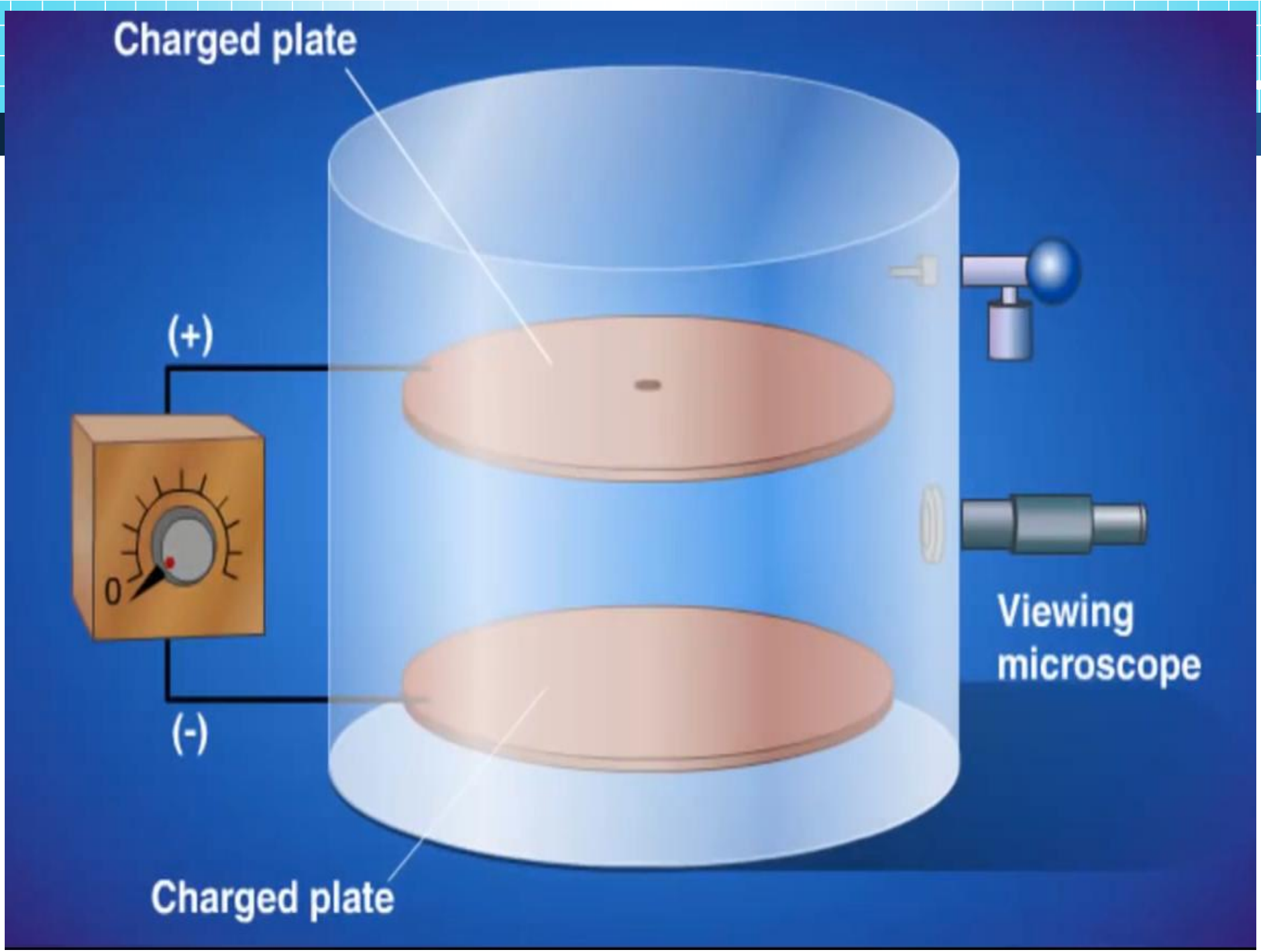


Robert Millikan

The oil drop

1916 – Robert Millikan determines the mass of the electron: 1/1840 the mass of a hydrogen atom; has one unit of negative charge


Charged plate
(+)
0
(-)
Viewing microscope
Charged plate


Charged plate
(+)
0
(-)
Viewing microscope
Charged plate

Rutherford's model

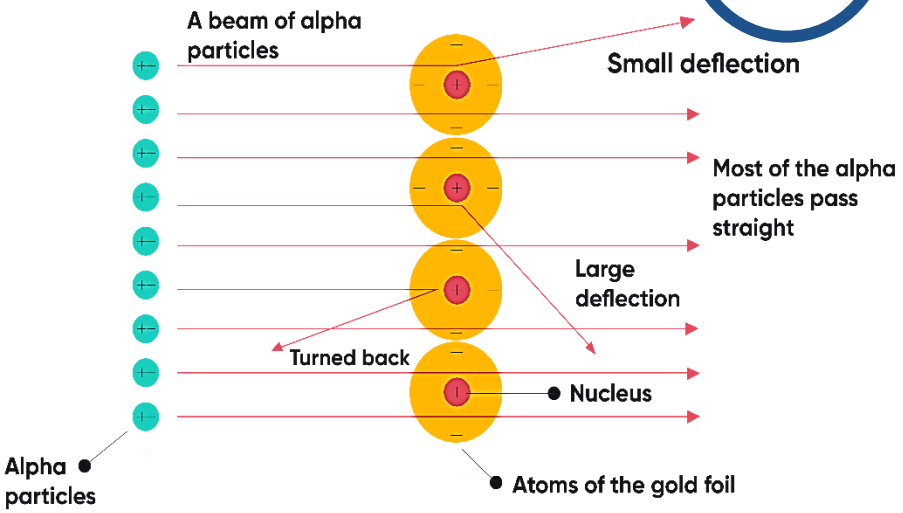
- Discovered the Nucleus and the Positive Protons
- Surmised atoms are made of mostly empty space
- Didn’t know about the Neutrons
- Famous Gold Foil Experiment

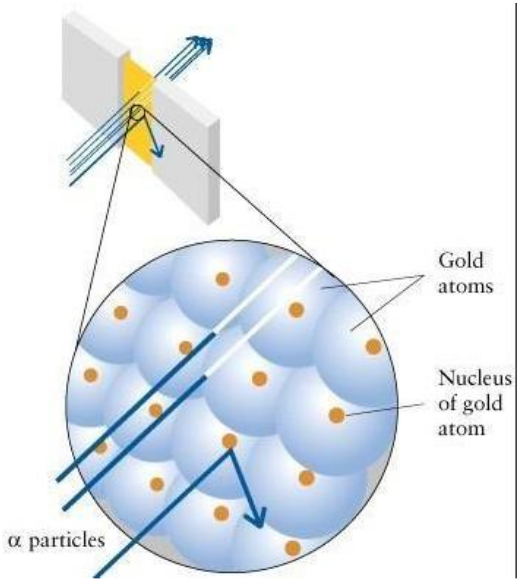


Further explanation of Nuclear Model

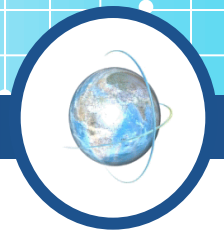
Most of the positively charged "bullets" passed right through the gold atoms in the sheet of gold foil without changing course at all.

Some of the positively charged "bullets," however, did bounce away from the gold sheet as if they had hit something solid. He knew that positive charges repel positive charges.





Nuclear Model

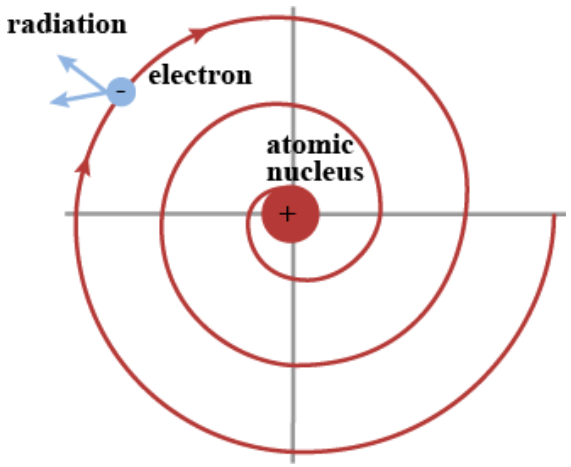


- Rutherford found that most (99%) of the alpha particles that he shot at the gold went straight through
- From these experiments Rutherford concluded that the atom had a dense positive core, with the rest composed of mostly empty space with the occasional negatively charged electron

note: this model completely changed the definition of atom

Difficulties with Rutherford's model

- Rutherford's electrons are undergoing a centripetal acceleration and so should radiate electromagnetic waves of the same frequency



- The radius should steadily decrease as this radiation is given off. The electron should eventually spiral into the nucleus but It doesn't
- The Rutherford model is unable to explain these phenomena.

Calculation of Rutherford's model

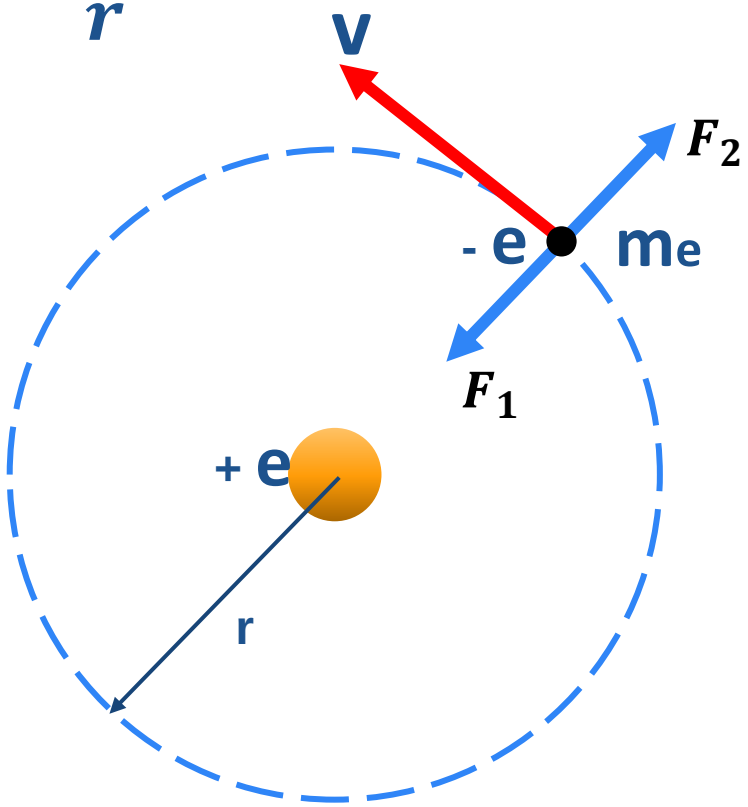
$$F_1 = \frac{|q_1 * q_2|}{4\pi * \varepsilon_o * r^2} \qquad F_2 = m\frac{v^2}{r}$$

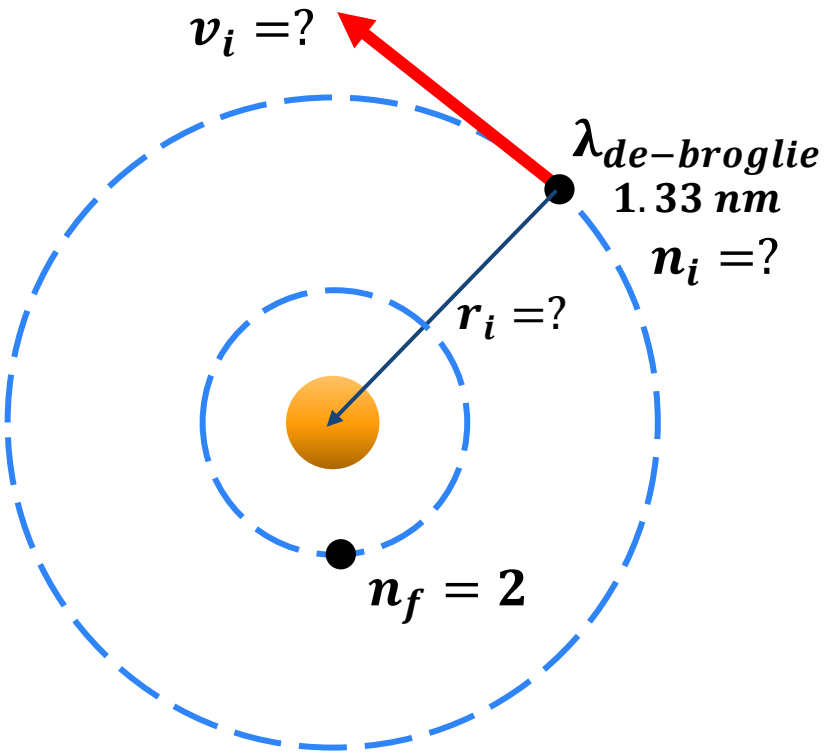
$$F_1 = F_2$$

$$\frac{|q_1 * q_2|}{4\pi * \varepsilon_o * r^2} = m\frac{v^2}{r}$$

$$\frac{e^2}{4\pi * \varepsilon_o * \cancel{r^2}} = m\frac{v^2}{\cancel{r}}$$

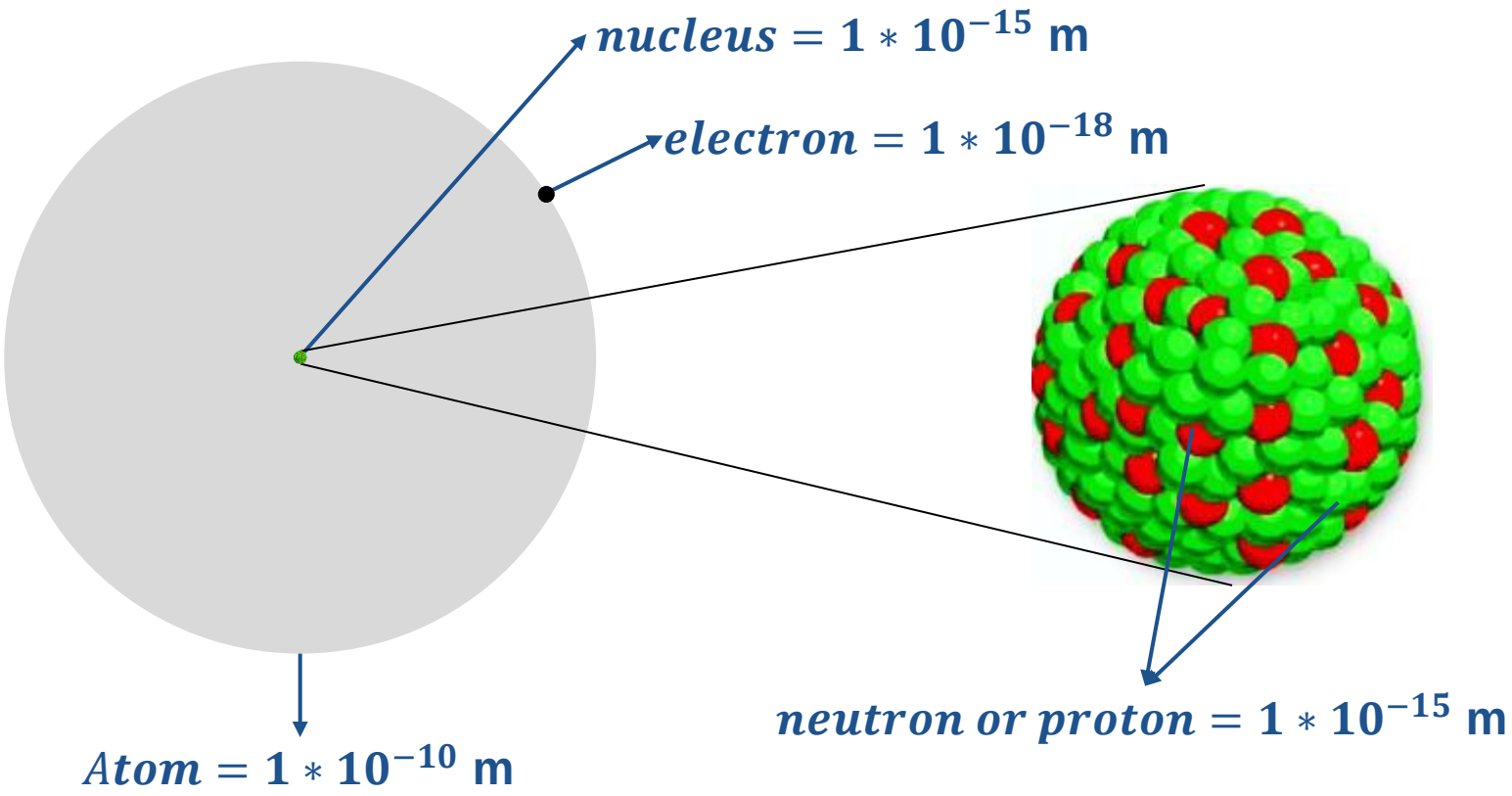
$$v = \sqrt{\frac{e^2}{4\pi\epsilon_o mr}}$$




$v_i = ?$
$\lambda_{de-broglie}$
$1.33\ nm$
$n_i = ?$
$r_i = ?$
$n_f = 2$

Introduction

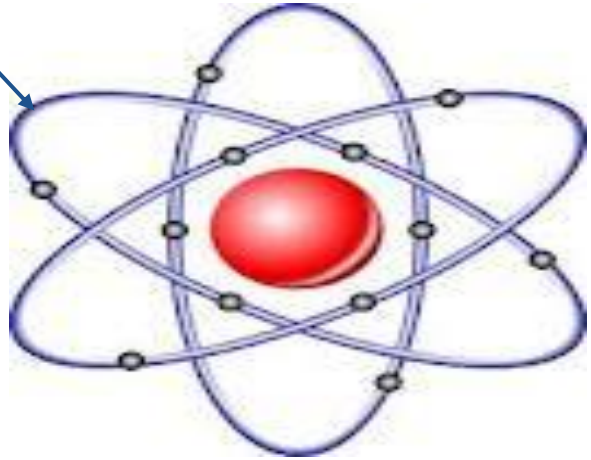
الذرة هي أصغر عنصر يمكن أن تنقسم له المادة ولا يمكن ان نرى الذرة باستخدام الميكروسكوب حيث تبلغ أبعاد الذرة ومكوناتها على النحو



Niels Bohr

- Discovered that electrons exist in several distinct layers or levels
- Travel around nucleus like planets travel around sun
- Electrons Orbit
- Electrons can jump between levels with energy being added/released



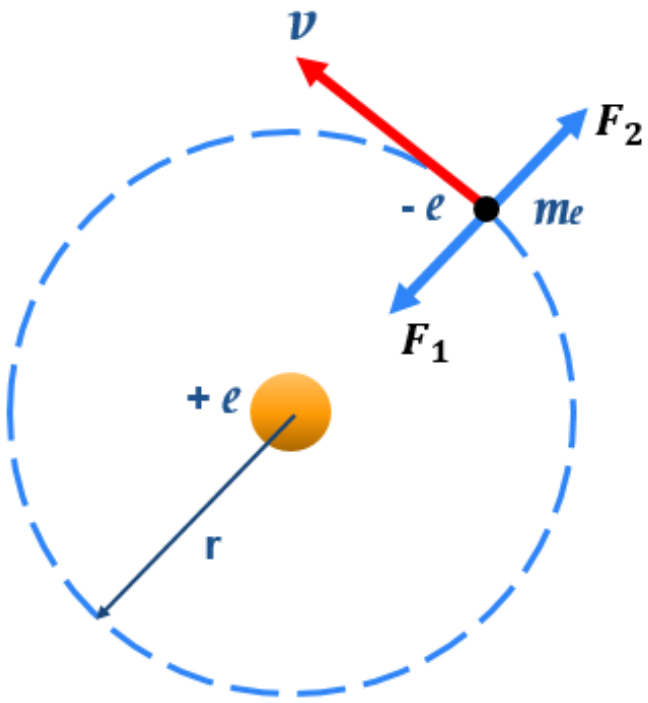


Bohr Model

- **Niels Bohr** proposed that electrons revolve around the central positive nucleus (like planets in the solar system)

$$\frac{e^2}{4\pi * \varepsilon_o * \cancel{r^2}} = m\frac{v^2}{\cancel{r}}$$

$$e^2 = 4\pi\varepsilon_o * rm * v^2 \quad \text{....(1)}$$



Bohr Model

المدار الذي يسلكه الإلكترون حول النواة هو المدار الذي يكون عزمه الزاوي P_θ (orbital angular momentum) تساوي عدد صحيح من ثابت بلانك مقسوم على 2π أي

$$P_\theta = mvr = \frac{nh}{2\pi} \qquad \text{where n = 1,2,3,.....}$$

$$let \qquad \hbar = \frac{h}{2\pi}$$

$$v = \frac{n\hbar}{mr} \qquad \text{....(2)}$$

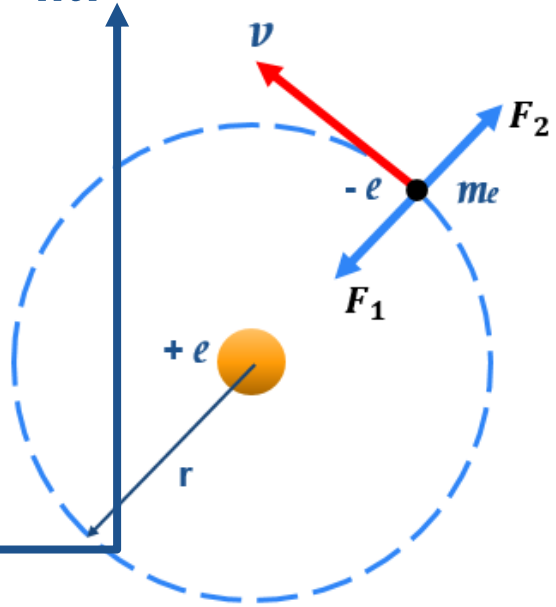
Bohr Model for Hydrogen Atoms

$$e^2 = 4\pi\varepsilon_o * rm * v^2 \quad \text{....(1)}$$

$$v = \frac{n\hbar}{mr} \quad \text{....(2)}$$

$$e^2 = 4\pi\varepsilon_o * rm * \left(\frac{n\hbar}{mr}\right)^2$$

$$e^2 = 4\pi\varepsilon_o * \cancel{rm} * \frac{n^2\hbar^2}{\cancel{m^2r^2}}$$



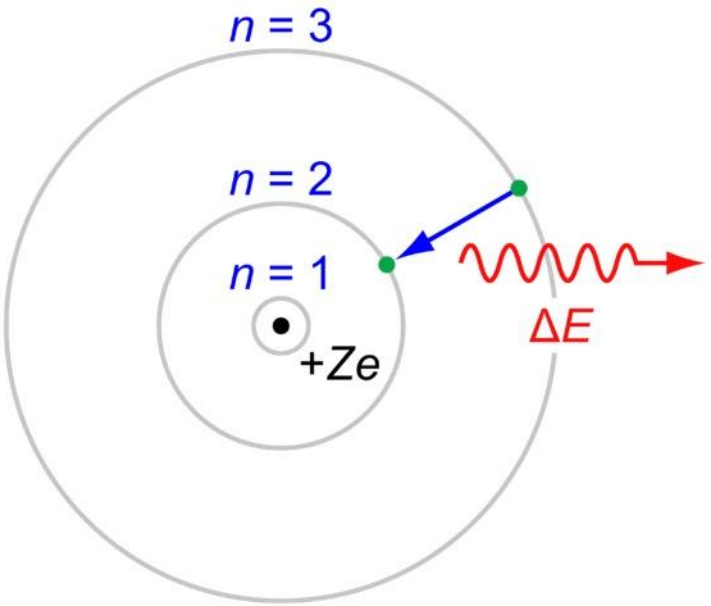
$$r = 4\pi\varepsilon_o * \frac{n^2\hbar^2}{me^2} \Rightarrow r = a_o n^2$$

$$a_o = 5.29 * 10^{-11}\ \text{m}$$

$$v = \frac{1}{4\pi\varepsilon_o} * \frac{e^2}{n\hbar}$$

Bohr Model





- بالرغم من أن الإلكترون يتحرك بعجلة في مداره الدائري حول النواة إلا ان في هذه المدارات المحددة بالفرضية الثانية فإن الإلكترون لا يشع أي طيف كهرومغناطيسي، وبالتالي فإن الطاقة الكلية للإلكترون تبقى ثابتة.
- ينبعث الطيف الكهرومغناطيسي إذا انتقل الإلكترون من مدار طاقته إلى مدار طاقته ثاني ويكون طاقة الفوتون المنبعث على شكل طيف كهرومغناطيسي تساوي فرق الطاقة بين المستويين.

$$hf = E_f - E_i$$

Electron Energy in Orbit for Hydrogen Atoms

The total energy of electron in orbit around the nucleus is the sum of potential energy and kinetic energy, that means:

E_{Total} = potential energy + kinetic energy

$$\text{potential energy} = -\frac{1}{4\pi\varepsilon_o}\frac{e^2}{r}$$

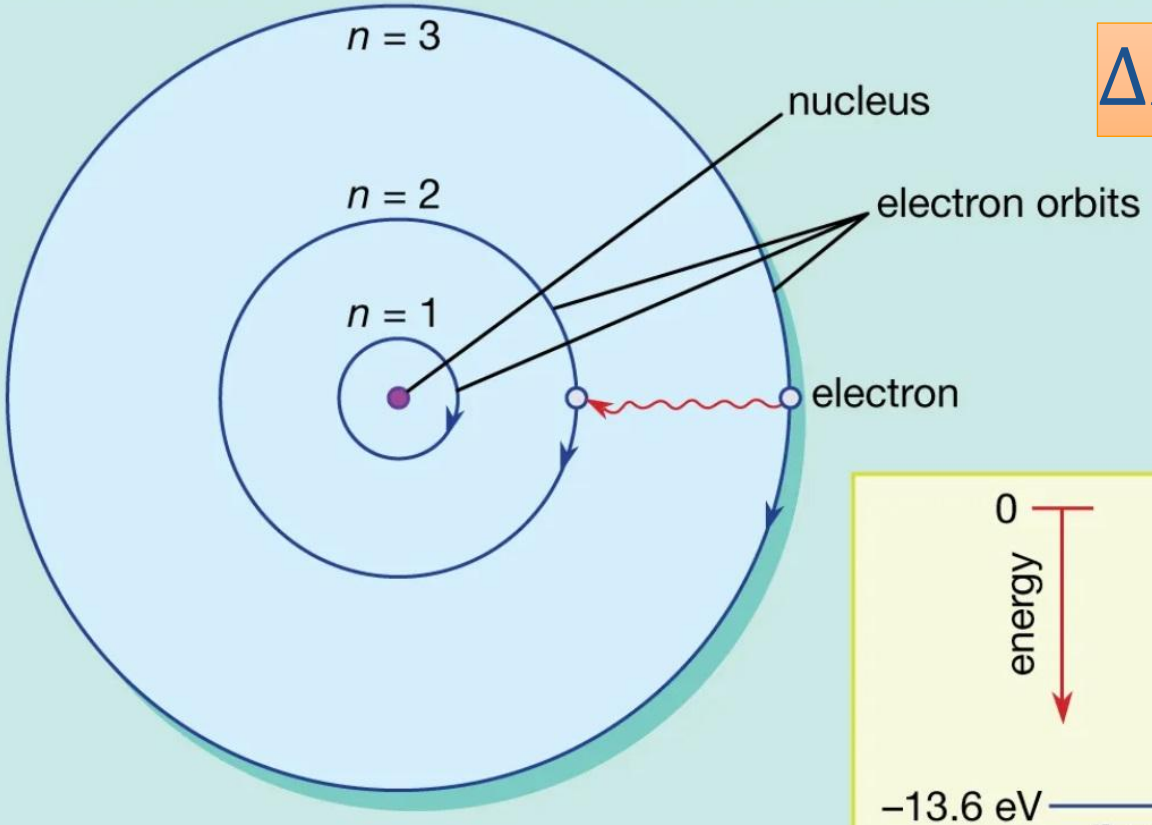
$$\text{kinetic energy} = \frac{1}{2}mv^2 = \frac{1}{2} * \frac{1}{4\pi\varepsilon_o}\frac{e^2}{r} = \frac{1}{8\pi\varepsilon_o}\frac{e^2}{r}$$

$$E_{Total} = -\frac{1}{8\pi\varepsilon_o}\frac{e^2}{r} \rightarrow E_n = -\frac{1}{8\pi\varepsilon_o}\frac{e^2}{a_o n^2} \rightarrow E_n = E_r\frac{1}{n^2}$$

$$E_r = -2.17 * 10^{-18} j = -13.6 eV$$

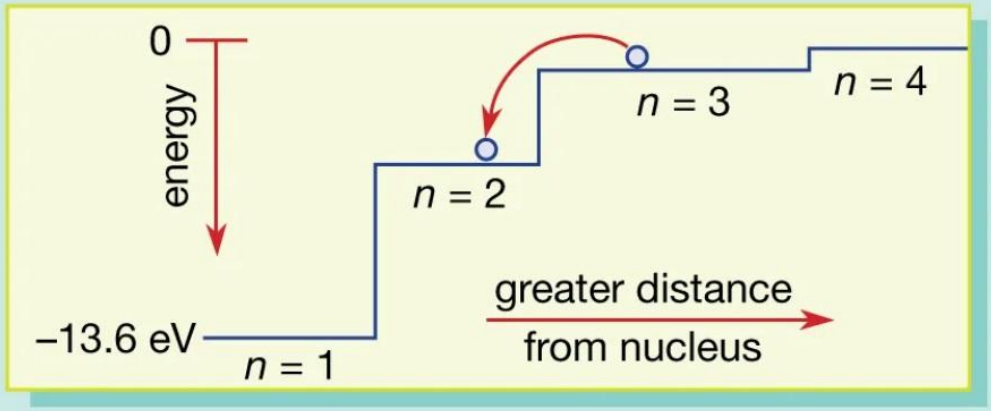
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$$\Delta E = E_f - E_i = hf$$

$$\Delta E = E_r \left(\frac{1}{{n_i}^2} - \frac{1}{{n_f}^2} \right)$$



Electron Energy in Orbit for Hydrogen Atoms

